Second Generation Mini-PEMS for the Application of Emissions Measurement

12th Annual International OSAR Conference
Riverside, CA

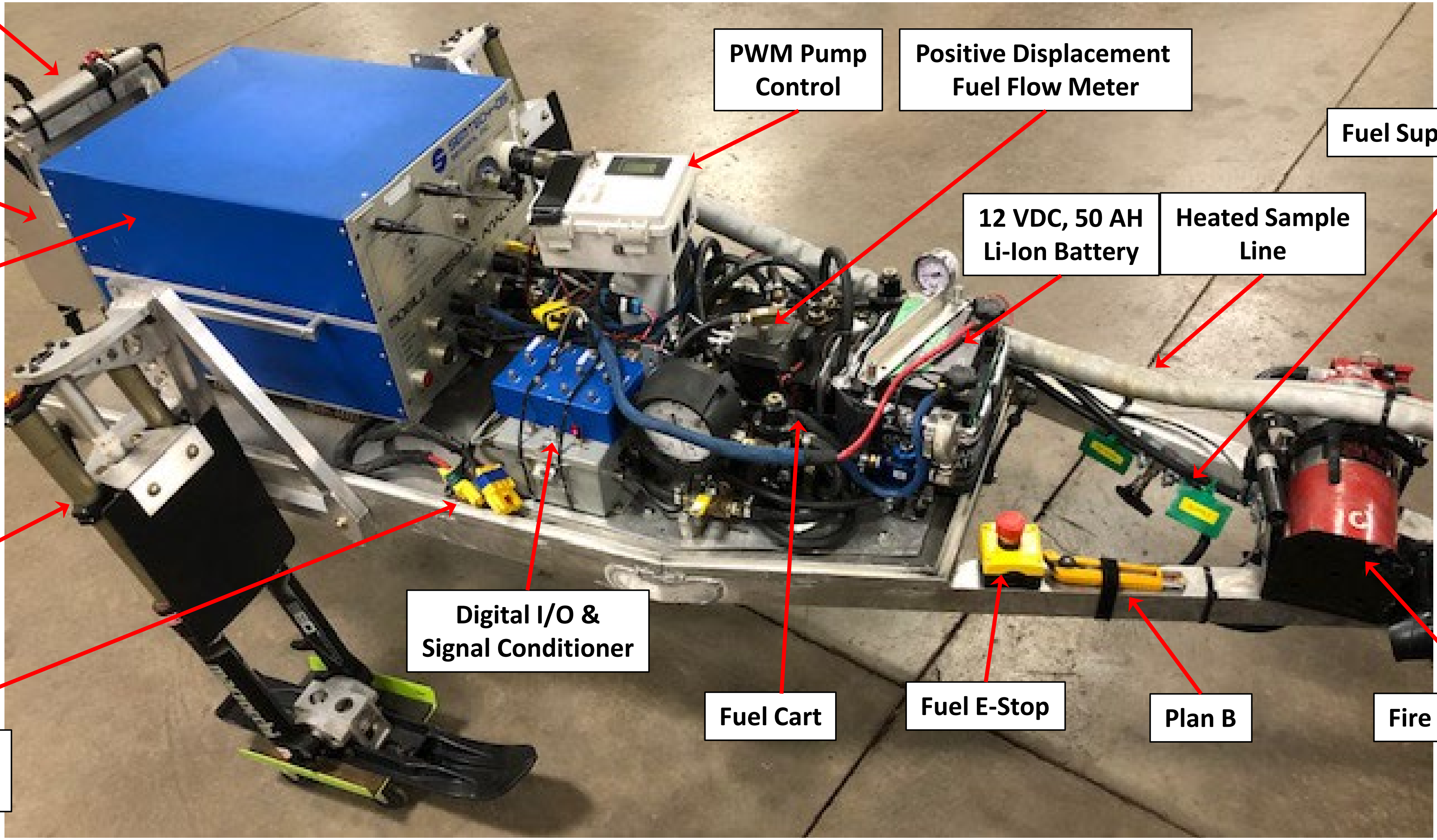
March 30th – 31st, 2023

Scott A. Miers, Faculty, Michigan Tech University
Brian J. Eggart, Research Engineer, Michigan Tech University – APS Labs

The Starting Point

- Michigan Tech began in-use emissions testing in 2009, at the SAE Clean Snowmobile Challenge
- In 2018, Michigan Tech was contracted to develop a procedure for conducting in-use emissions testing of snowmobiles, for the European Commission - Joint Research Center in Italy
- A pull-behind sleigh was used to measure in-use emissions of four snowmobiles

On-Snow PEMS Testing: Emissions Sleigh*



*Additional specifications provided in supplemental slides

APS LABS

Michigan Tech

Why Did Michigan Tech Develop a Mini-PEMS?

- The pull-behind sleigh impacted the vehicle operation
  - Complete pull-behind system is approximately 360 lbs
  - Deteriorated handling (speed and terrain) with limited operational environment (groomed trail use)
  - Increased fuel consumption (added weight and drag) → increased emissions (higher power consumption)
- Current, compact solutions (Mini-PEMS) have at least one of the following issues:
  - No measurement of total hydrocarbons and/or methane or limited measurement range
  - Inconsistent test-to-test results
- Michigan Tech decided to build a Mini-PEMS that easily installed on snowmobiles for in-use emissions testing, provided five-gas analysis with high hydrocarbon measurement capability, and produced consistent and repeatable results
  - Additionally, it was designed to be an excellent fit for other small vehicles such as:
    - On and off-highway motorcycles, ATV/UTV's, and small watercraft

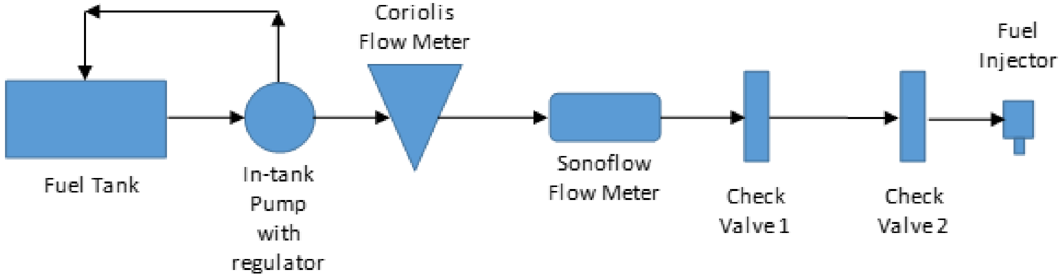
Note: the system has progressed from a screening tool to a compliance-level device

Improvements from Sleigh → Gen1

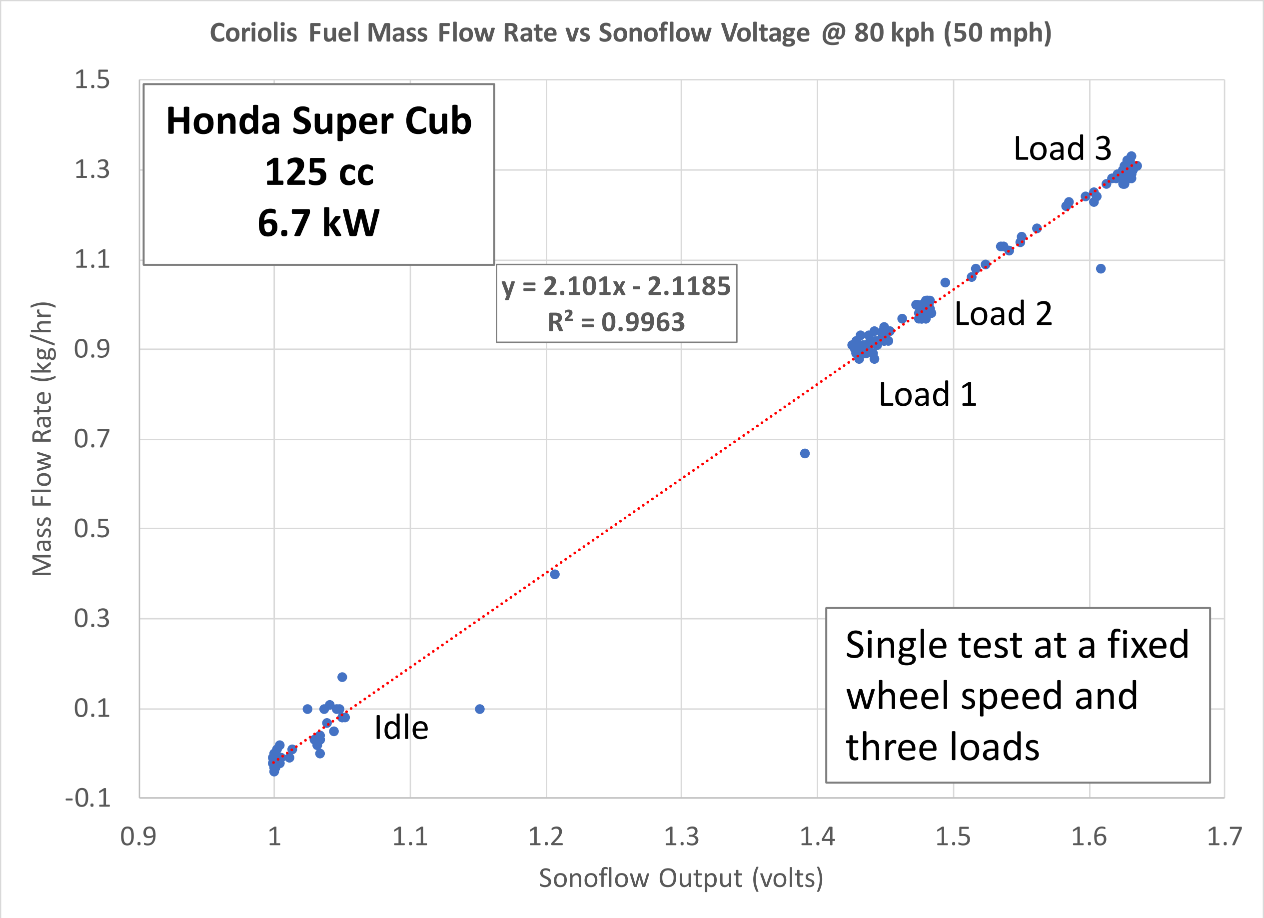
- Fuel flow
  - Sleigh system was accurate but very heavy (>35 lbs)
  - Exhaust flow measurement is common with PEMS, but nearly impossible on small engines
    - Very high exhaust pressure pulsations are present, due to reduced cylinder count
  - The first fuel flow sensor (Keyence, FD-XS8) was highly non-linear at low flows
- Weight reduction
  - Reduced overall weight from ***360 lbs to 44 lbs***
    - Battery, fuel system, analyzer, elimination of sleigh
- Measurement range of total hydrocarbons
  - Semtech-DS has a limit of 40,000ppmC1
  - Gen1 had the capability to measure up to ***120,000ppmC1***

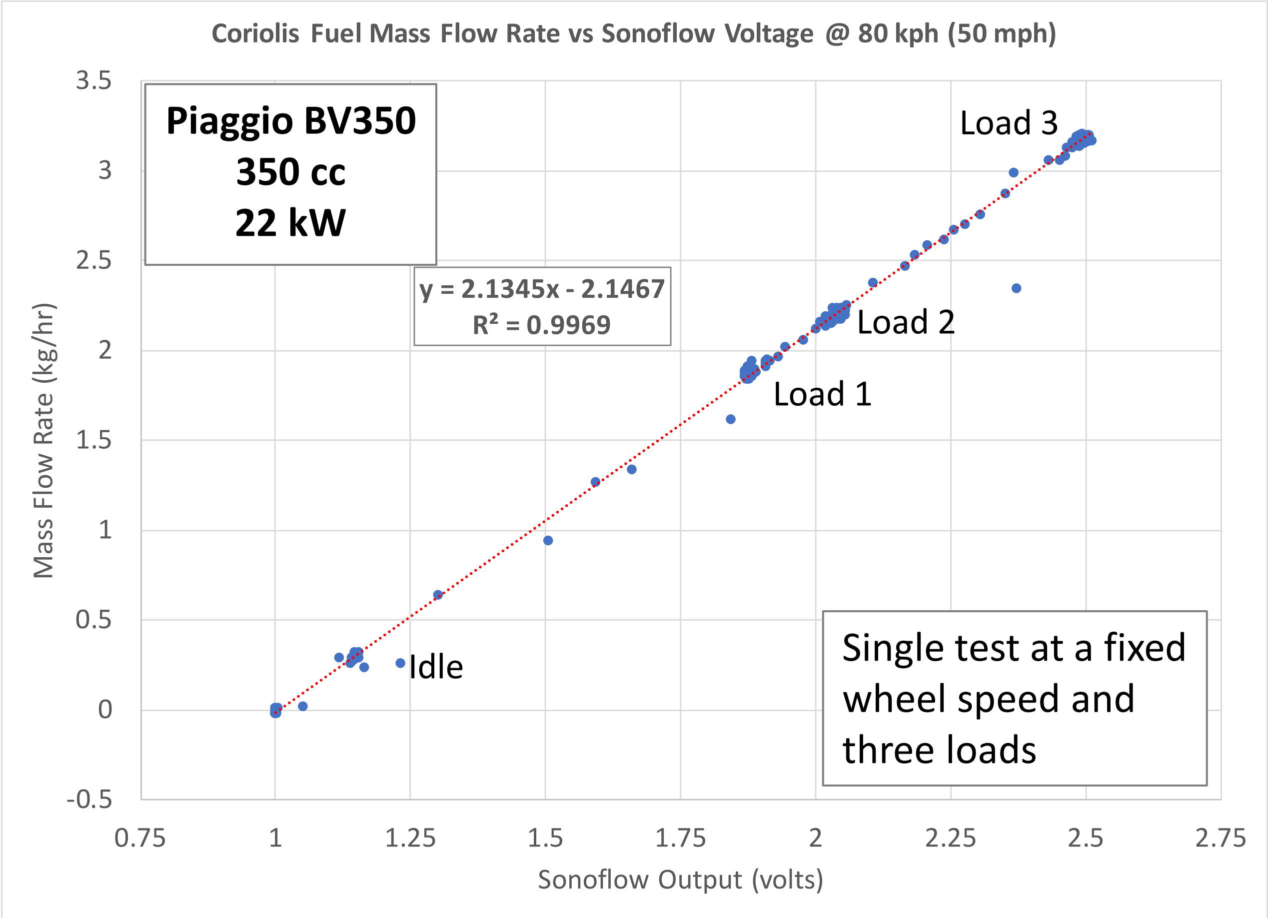
New Fuel Flow Sensor Validation

- An inline flow sensor (IL.52) produced by Sonotec (Germany) and distributed in the US was chosen to solve the low flow nonlinearity issues
- Sensor provides accurate, linear flow measurement at very low fuel flow rates
  - Addresses problem area of exhaust flow meters and first ultrasonic flow meter
- A MicroMotion CMF010 Coriolis meter was used as the reference sensor
- Initial testing of the sensor was performed in a laboratory environment
  - Flow measurement did not agree with the Coriolis meter when moved from lab to motorcycle
  - Pulsating flow from fuel injector affects measurement thus in-use correlation is necessary
- A linear correlation was determined using the voltage output from the Sonoflow and fuel flow rate from the Coriolis flow meter



Correlation Data for Honda & Piaggio Motorcycles



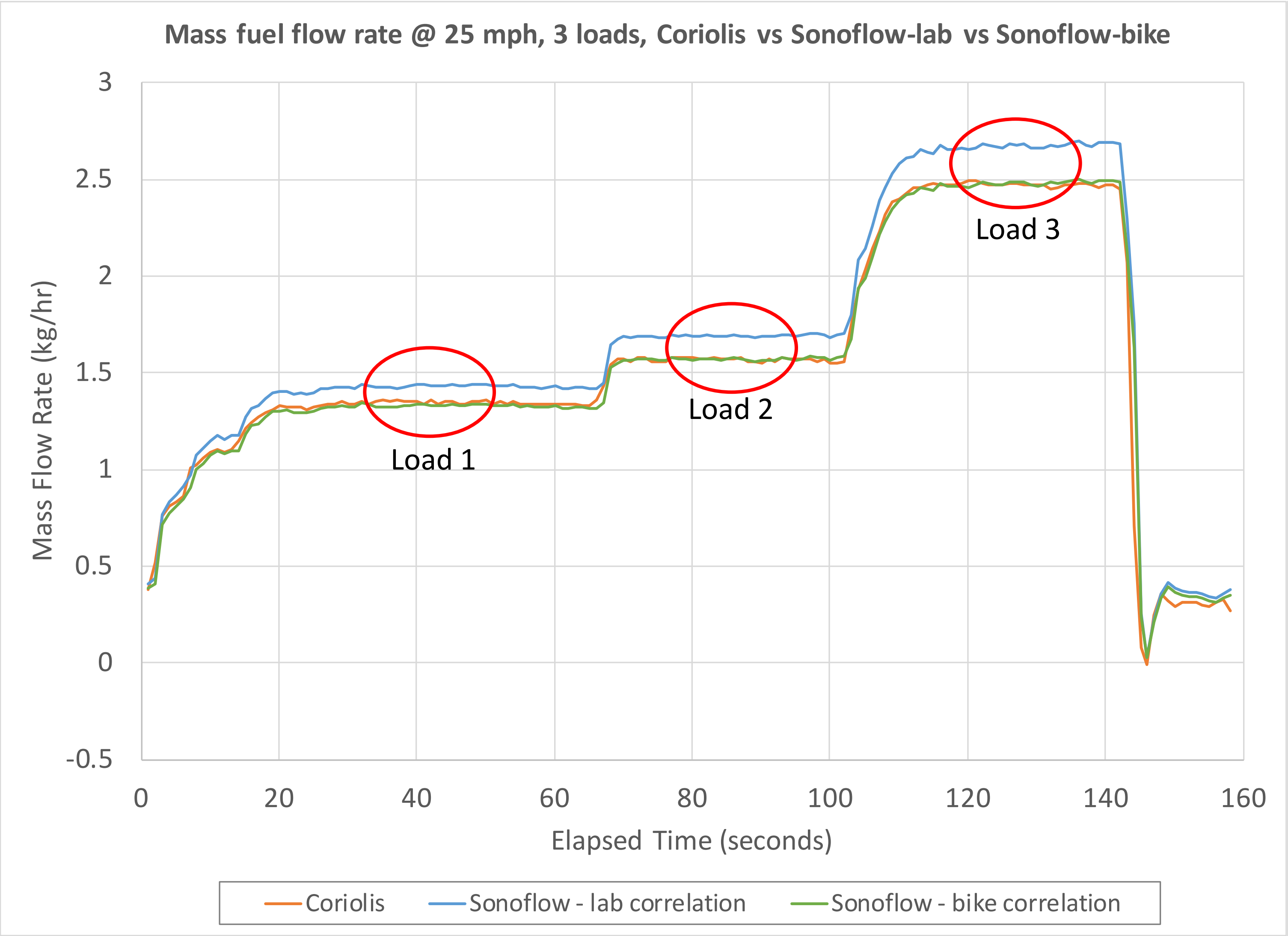


- Linear correlations are quite similar for these two motorcycles
- Additional data from a larger motorcycle is needed to determine if correlation will need to be modified
- Would be similar to changing the tube diameter for an EFM, based on engine exhaust flow

APS LABS

Michigan Tech

Fuel Flow Data



Lab Correlation

- The offset in steady-state fuel flow measurement is caused by the pulsations generated by the fuel injector.
- These pulsations were not present during the laboratory calibration of the Sonoflow meter (blue line).

Bike Correlation

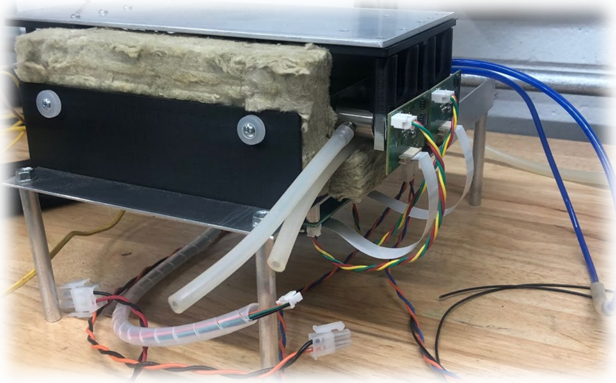
- The correlation generated using the motorcycle produces effective results for the Sonoflow meter

Improvements from Gen1 → Gen2

- Weight reduction
  - Typical single cylinder motorcycles weigh around 250 - 400 lbs
  - Gen1 weighs 44 lbs (10-15% of the total vehicle weight)
    - This can negatively affect the operation of smaller vehicles
- Hydrocarbon measurements
  - Determination of NMHC is required for Euro5 emissions regulations of on-highway motorcycles
  - Improve total hydrocarbon measurement accuracy

Gen1

Gen2



How will the Weight of Gen2 be Reduced?

- Current mini-PEMS (Gen1) is 44 lbs
- Target weight for Gen2 is **25 lbs**
- Weight reduction will occur by:
  - Downsizing the battery
    - Current battery is 12 VDC, 35 AH, 11 lbs
    - Gen2 battery is 12 VDC, 20 AH, 5 lbs
    - ***This is a weight savings of 6 lbs***
  - Eliminating the Pelican case and replacing with softshell case
    - Pelican case weighs 13 lbs
    - Softshell case weights 5 lbs
    - ***This is a weight savings of 8 lbs***
  - Consolidating the electronics, relays, CPU, and wiring
    - ***This is a weight savings of ~5 lbs***

Measuring Hydrocarbons with NDIR Technique

- CO_2 and CO have historically been measured using a NDIR analyzer
- Both of these constituents have unique absorption bands and thus a very narrow filter can be used to accurately measure the concentration
- The term "hydrocarbons" includes a wide range of carbon and hydrogen molecules, all possessing slightly different absorption bands
- Therefore, a compromise must be made to target the anticipated largest molecules, often missing the outliers completely
  - This is typically C_3H_6 and C_3H_8

Solution:

- Implement filters with different characteristics to broaden the range of hydrocarbons able to be measured
- Heat the sample path to ensure hydrocarbons stay in the gaseous phase

Methane Measurement and NMHC Determination

- Methane is a weak absorber of IR light
  - Measurement accuracy declines as the concentration reduces
- The determination of NMHC is substantially more involved than simply subtracting the methane concentration from the total hydrocarbon concentration

Solutions:

- A second, longer sample cell has been incorporated with special filters to target and improve methane measurement
- Propriety software has been utilized to accurately compute the NMHC given methane and total hydrocarbon readings

Next Steps

- Gen2 mini-PEMS
  - Next 2-4 weeks
    - Pre-filter and sample pump mounting
    - Calibration
    - Stationary data collection (chassis dyno)
- Preparation of Gen2 for on-road testing
  - Next 4-8 weeks
    - Design and fabricate interface bulkhead
    - Purchase enclosure
    - Finalize mounting mechanism
- Larger motorcycle (1200cc)
  - Next 3-5 weeks
    - Further validation of fuel flow sensor correlation

APS LABS

Michigan Tech

Acknowledgements

- Environment and Climate Change Canada
  - Thank you for supporting the development of the Gen1 system
- California Air Resources Board (CARB)
  - Financial and technical support for development and testing of 2nd generation mini-PEMS
- US Environmental Protection Agency
  - Grateful for material loans, technical advice, project tracking
- MEDC, Michigan State University ADVANCE grant
  - Helping to support additional testing of Gen2 mini-PEMS
- Infrared Industries
  - Thank you for ongoing technical and system development support

Thank you for your attention!

Scott A. Miers, Associate Professor

1400 Townsend Drive

Houghton, MI 49931

Office: (906) 487-2709

Cell: (630) 310-0958

Email: samiers@mtu.edu

Brian J. Eggart, Research Engineer

32199 Airpark Blvd

Calumet, MI 49913

Office: (906) 487-2591

Cell: (906) 370-9522

Email: bjeggart@mtu.edu

Supplemental Slides:

Fuel Flow Correlations

Piaggio BV350

- January 4th, 2023, average of four tests: Fuel mass flow rate (kg/hr) = 2.0199 * Sonoflow_volts - 2.026
- January 11th, 2023, average of four tests: Fuel mass flow rate (kg/hr) = 1.9389 * Sonoflow_volts - 1.946
- February 1st, 2023, average of four tests: Fuel mass flow rate (kg/hr) = 2.0677 * Sonoflow_volts – 2.075

- Average of 3 Correlations: **Fuel mass flow rate (kg/hr) = 2.009 * Sonoflow_volts – 2.015**

Honda SuperCub

- March 1st, 2023, average of four tests: Fuel mass flow rate (kg/hr) = 2.1576 * Sonoflow_volts – 2.172
- March 9th, 2023, average of four tests: Fuel mass flow rate (kg/hr) = 2.1417 * Sonoflow_volts - 2.152

- Average of 2 Correlations: **Fuel mass flow rate (kg/hr) = 2.150 * Sonoflow_volts – 2.162**

Sonoflow and Coriolis Specifications

Specification	Sonoflow IL.52	MicroMotion CMF010
Weight	370 grams	4,600 grams
Dimensions	148 mm x 59 mm x 46 mm (LxWxH)	320 mm x 53 mm x 318 mm (LxWxH)
Flow range	0 - 3,000 mL/min	0 – 110 kg/hr
Output	4-20 mA	4-20 mA
Measurement Technique	Ultrasonic	Coriolis